SUNGUARD:

A ROOFING TILE FOR NATURAL COOLING

FEASIBLITY ANALYSIS AND FINAL EISG REPORT

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ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM

FEASIBILITY ANALYSIS REPORT (FAR)

SUNGUARD:
A ROOFING TILE FOR NATURAL COOLING

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LEGAL NOTICE

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million of which $2 million/year is allocated to the Energy Innovation Small Grant (EISG) Program for grants. The EISG Program is administered by the San Diego State University Foundation under contract to the California State University which is under contract to the Commission.

The EISG Program conducts four solicitations a year and awards grants up to $75,000 for promising proof-of-concept energy research.

PIER funding efforts are focused on the following six RD&D program areas:

- Residential and Commercial Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

The EISG Program Administrator is required by contract to generate and deliver to the Commission a Feasibility Analysis Report (FAR) on all completed grant projects. The purpose of the FAR is to provide a concise summary and independent assessment of the grant project using the Stages and Gates methodology in order to provide the Commission and the general public with information that would assist in making follow-on funding decisions (as presented in the Independent Assessment section).

The FAR is organized into the following sections:

- Executive Summary
- Stages and Gates Methodology
- Independent Assessment
- Appendices
    - Appendix A: Final Report (under separate cover)
    - Appendix B: Awardee Rebuttal to Independent Assessment (Awardee option)

For more information on the EISG Program or to download a copy of the FAR, please visit the EISG program page on the Commission's Web site at:
http://www.energy.ca.gov/research/innovations

or contact the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

For more information on the overall PIER Program, please visit the Commission's Web site at http://www.energy.ca.gov/research/index.html.

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Introduction

In hot climates where residential energy use is dominated by cooling needs, a cool roof can significantly reduce air conditioning costs. Most residential roofing systems have highly absorptive surfaces that conduct large amounts of heat into the attic space. Light colored roofing material has a positive effect on roof and attic temperatures. However there is no product on the market that offers both cool-roof benefits and photovoltaic (PV) electricity generation. Further, most PV systems are not aesthetically attractive when installed on sloped residential roofs. A need exists for an aesthetically pleasing, cool roofing product that supports PV integration.

In 1997, approximately 47% of all residences in the western United States had some form of air conditioning installed. Most new residences built in the hot interior valleys of California are equipped with central air conditioning. According to the California Energy Commission, air conditioning consumed ~8% of all residential electricity in1996. As more people move to hot inland areas the electricity used for residential cooling is increasing. Reducing the roof and attic temperatures can have a major effect of the amount of thermal energy that must be removed by the air conditioning system. Residential air conditioners often add to the peak demand in late afternoon when commercial and industrial demand also peaks. Reducing the roof and attic temperatures of residences in hot climates could lead to significant reductions in the electricity demand at peak hours.

The researcher in this project attempted to prove the feasibility of a new roofing material design that incorporates natural roof cooling, PV integration and aesthetic appeal. Natural cooling was achieved by providing two separate roof layers separated by an air layer. Proprietary supports maintained the separation. The researcher investigated materials for the top and bottom layer of the cooling channel as well as the use of a radiant barrier. Upon selection of the materials the researcher proposed building and testing prototype roofing material to demonstrate the cooling capabilities of the design. For building-integrated (new construction) applications, the researcher proposed a PV- and non-PV roofing tile to cover the entire roof. Non-PV roofing tiles were proposed to fill in areas where PV tiles would provide little electricity. Enhanced thermal benefits would be obtained over the entire roof area. The researcher intended to give the PV array an appearance of being integrated into the roof. The researcher anticipated that a similar design could be used in retrofit applications on existing buildings. This project included laboratory evaluation and field-testing of the building integrated product.

Project Objectives:

The goal of this project was to prove the feasibility of a novel ventilated roofing tile incorporating a radiant barrier and proprietary supports that could be used with or without PV modules on residential roofs. The following project objectives were established:

1. Optimize the ventilated roofing tile geometry and materials to achieve a cost target of $2.50 per square foot (sf).
2. Determine life of ventilated roof material through accelerated life testing. Material should demonstrate the potential for 20-year life.
3. Reduce heat flow through the roofing material by 90%.

Project Outcomes:

1. The researcher determined tile geometry through laboratory and field tests. The researcher selected materials for that prototype design. While tests indicated that most performance goals were met, the researcher did not meet cost targets. The researcher was not able to incorporate fully fire resistance materials within the price target.
2. The researcher installed a prototype 288 W PV integrated module on an outdoor test roof at an independent laboratory. Thermal and electrical performance data were collected. The array consisted of 34 tiles, some with PV modules and some without. The researcher did not note any durability issues during the outside test period. Because the materials selected for the test articles would not be used in production, the researcher did not conduct accelerated life testing.
3. The researcher determined that heat flow through the ventilated roofing tile was reduced by 90% over the control material.

Conclusions:

1. Materials selected for initial prototypes will not meet cost goals. Further research is needed to identify materials that will meet all performance criteria including fire resistance within the cost target of $2.50/sf.
2. The PA recommends accelerated testing of ventilated roofing tiles once the researcher selects materials that meet the cost target.
3. The researcher successfully reduced heat transfer through the roofing material to the attic space. When PV modules are added to the ventilated roof tiles, total energy savings of 28%-35% could be achieved for typical residences in target markets. Target markets are new construction and retrofit (re-roofing) applications over existing asphalt shingle roofs, on buildings in hot, cooling-dominated climates. These climates include most hot, inland valleys of California. The building-integrated design should be designed and built as modular components to reduce installation costs. Significant engineering work remains to develop this product configuration.

The project final report was submitted with an extensive proprietary appendix. The published final report (Appendix A) does not include the information necessary to support the conclusions drawn. The reader is referred to the project researcher for access to any proprietary data.

Benefits to California

While it is not ready for the market at this time, when it is fully developed and if project objectives are met, residential energy consumers will benefit from this product through lower energy bills and protection from system outages because of reduced peak loads. Small commercial and industrial buildings may be able to take advantage of this product depending on the architecture of the buildings. The electrical grid will be less congested and thus more stable. Additional environmental benefits derive from the renewable (PV) electricity that is generated in the state. This additional electricity offsets electricity produced by conventional combustion electrical generators.

Recommendations:

The PA recommends continuing the product development once the researcher has developed possible schemes to meet product cost and performance goals. Suggested research steps include:

- Conduct further materials and tile geometry research to meet cost and performance goals
- Perform accelerated life tests (mechanical, water resistance, fire and UV resistance)
- Determine potential energy savings when applied to houses in specific climate zones
- Obtain commercially critical certifications (e.g. UL, ICBO)
- Develop distribution channels and partnerships with developers and roofing contractors.

Stages and Gates Methodology

The California Energy Commission utilizes a stages and gates methodology for assessing a project's level of development and for making project management decisions. For research and development projects to be successful they need to address several key activities in a coordinated fashion as they progress through the various stages of development. The activities of the stages and gates process are typically tailored to fit a specific industry and in the case of PIER the activities were tailored to be appropriate for a publicly funded energy research and development program. In total there are seven types of activities that are tracked across eight stages of development as represented in the matrix below.

Development Stage/Activity Matrix

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Activity 1								
Activity 2								
Activity 3								
Activity 4								
Activity 5								
Activity 6								
Activity 7								

A description the PIER Stages and Gates approach may be found under "Active Award Document Resources" at: http://www.energy.ca.gov/research/innovations and are summarized here.

As the matrix implies, as a project progresses through the stages of development, the work activities associated with each stage needs to be advanced in a coordinated fashion. The EISG program primarily targets projects that seek to complete Stage 3 activities with the highest priority given to establishing technical feasibility. Shaded cells in the matrix above require no activity, assuming prior stage activity has been completed. The development stages and development activities are identified below.

Development Stages:	**Development Activities:**
Stage 1: Idea Generation & Work Statement Development	Activity 1: Marketing / Connection to Market
Stage 2: Technical and Market Analysis	Activity 2: Engineering / Technical
Stage 3: Research & Bench Scale Testing	Activity 3: Legal / Contractual
Stage 4: Technology Development and Field Experiments	Activity 4: Environmental, Safety, and Other Risk Assessments / Quality Plans
Stage 5: Product Development and Field Testing	Activity 5: Strategic Planning / PIER Fit - Critical Path Analysis
Stage 6: Demonstration and Full-Scale Testing	Activity 6: Production Readiness / Commercialization
Stage 7: Market Transformation	Activity 7: Public Benefits / Cost
Stage 8: Commercialization	

Independent Assessment

For the research under evaluation, the Program Administrator assessed the level of development for each activity tracked by the Stages and Gates methodology. This assessment is summarized in the Development Assessment Matrix below. Shaded bars are used to represent the assessed level of development for each activity as related to the development stages. Our assessment is based entirely on the information provided in the course of this project and the final report. Hence it is only accurate to the extent that all current and past work related to the development activities are reported.

Development Assessment Matrix

Stages / Activity	1 Idea Generation	2 Technical & Market Analysis	3 Research	4 Technology Develop-ment	5 Product Develop-ment	6 Demon-stration	7 Market Transfor-mation	8 Commer-cialization
Marketing								
Engineering / Technical								
Legal/ Contractual								
Risk Assess/ Quality Plans								
Strategic								
Production. Readiness/								
Public Benefits/ Cost								

The Program Administrator's assessment was based on the following supporting details:

Marketing/Connection to the Market.

Initial market research was conducted. The researcher identified markets throughout California, and in foreign countries with similar weather conditions. The PA recommends additional market research to further define customer needs. That study should also investigate market potential at varying price points.

Engineering/Technical.

The researcher developed preliminary product drawings for a roofing product based on the results of the technical feasibility tests. The product's estimated low thermal absorption indicates technical feasibility of the product concept. Other goals, such as the cost target, have not yet been met. A test plan has been written for future field tests. The researcher plans life cycle tests.

Legal/Contractual.

A patent has been issued for this product. Subsequent patents are being developed.

Environmental, Safety, Risk Assessments/ Quality Plans.

The researcher did not develop a quality plan, but did conduct a product life cycle analysis for potential materials. The researcher analyzed five areas of risk: market, regulatory, technology, management and execution, and competition. The researcher developed plans to resolve each risk area. The PA recommends that a quality plan be drafted prior to initiation of Stage 4 development activity. Quality planning addresses Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, Product Safety, and Environmental**.**

Strategic.

This product has no known critical dependencies on other projects under development by PIER or elsewhere.

Production Readiness/Commercialization.

PowerLight Corporation plans to produce and take this product to market. The PA has not received a business and production plan relative to the ventilated roof tile. No sales projection data are yet available. When sales data are available, they will be submitted to the California Energy Commission.

Public Benefits

Public benefits derived from PIER research and development are assessed within the following context:

- Reduced environmental impacts of the California electricity supply or transmission or distribution system
- Increased public safety of the California electricity system
- Increased reliability of the California electricity system
- Increased affordability of electricity in California

The primary public benefit offered by the proposed technology is to make electrical energy more affordable in California. This will be accomplished by reducing electrical consumption at times of peak power demand, especially in the cooling dominated regions of California. This will also reduce the peak utility loads and risk of blackouts.

This analysis has a risk factor. The targeted production cost of $2.50 per square foot assumes that economies of scale can be achieved allowing the targeted cost to be achieved. This assumption is a risk factor that would need to be further assessed in the marketing plan.

Program Administrator Assessment:

After taking into consideration (a) research findings in the grant project, (b) overall development status as determined by stages and gates, and (c) relevance of the technology to California and the PIER program, the Program Administrator has determined that the proposed technology should be considered for follow on funding within the PIER program.

Receiving follow on funding ultimately depends upon (a) availability of funds, (b) submission of a proposal in response to an invitation or solicitation, and (c) successful evaluation of the proposal.

Appendix A: Final Report (under separate cover)

Appendix B: Awardee Rebuttal to Independent Assessment (none submitted)

ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM

EISG FINAL REPORT

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Legal Notice

Inquires related to this final report should be directed to the Awardee (see contact information on cover page) or the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

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Abstract

A new concept for a residential roofing product that combines the benefits of a cool roof with photovoltaic (PV) electricity generation was developed and independently evaluated at an independent laboratory. The product consists of a PV module or architectural panel as the top substrate, mounted to a backing material that serves as the weatherproofing layer of the rooftop. A ventilated air gap between the two substrates, combined with other assembly elements (proprietary), provide insulation to the roof. Product performance was evaluated through indoor tests and outdoor field tests, on experimental roofs side by side with asphalt shingle control roofs. Monitoring of heat flow into the model attic spaces and PV performance showed that the product nearly eliminated heat flow into the attic during periods of hot weather. Building energy simulations showed that the product could save homeowners in target markets approximately $100-250/year. Target markets include new construction for the building-integrated version of the product, as well as retrofit and re-roofing applications on asphalt shingle roofs, on buildings in hot (cooling-dominated) climates**.**

Key Words:

Cool roof, ventilate,

Executive Summary

Introduction

Under this EISG grant, PowerLight developed and field-tested a new residential roofing product called SunGuard™.

SunGuard is conceived of as a family of products. For building-integrated (new construction) applications, a PV- and non-PV roofing tile are used together to cover the entire roof. Non-PV roofing tiles are used to fill in areas not covered by the PV tiles, so that thermal benefits are obtained over the entire roof area, and to give the PV array an integrated appearance. A spin-off of this product is a version for retrofit applications on existing shingle roofs. Work under this contract involved field-testing and evaluation of the building integrated product; the optimized tile geometry was also incorporated into the retrofit tile concept.

Project Objectives:

1. Optimize SunGuard tile geometry and materials, and perform accelerated life testing;
2. Validate product performance at an independent lab;
3. Estimate energy savings to homeowners and refine target markets;
4. Develop advanced designs for both building-integrated and retrofit applications.

Project Outcomes:

1. Materials that met cost goals and most performance goals for this project were selected. Tile geometry for first generation, building-integrated prototypes was determined through indoor and field tests.

2. A prototype SunGuard system (288W) was installed at an independent lab, on an outdoor test roof, and thermal and electrical performance data was collected for nine months; the array consisted of 34 tiles, a combination of SunGuard (without PV) and SunGuard-E (with PV).

3. Reduced energy demand and on-site electricity production were modeled for a typical residence with and without a 4kW SunGuard system, using a computer model and empirical test results, to estimate energy savings. Target markets were further refined.

4. A first-generation design was developed for retrofit applications. Based on field test results, the building-integrated design was refined.

Conclusions:

- Materials selected for initial prototypes will not meet all performance criteria. Further research is needed to identify materials that will meet all criteria, including the cost-target of $2.50/sf when manufactured in high volumes.
- As shown in internal and independent testing, SunGuard nearly eliminates heat flow through the roof during the critical hours of AC peak demand and utility peak demand.

- Thermal properties can reduce air conditioning loads by 90%. Added to electricity generation from the PV, SunGuard may result in total energy savings of 28%-35% for typical residences in target markets.
- Target markets are new construction for the building-integrated version of the product, and retrofit (and re-roofing) applications over existing asphalt shingle roofs, on buildings in hot, cooling-dominated climates. These climates include the hot, inland areas of California; Arizona, Hawaii, Florida. Europe and Japan are also target markets, due to extensive public incentives for PV.
- Retrofit designs will likely use standoffs to integrate PV with typical asphalt shingles. The modified building-integrated design will likely incorporate a "modular pan."
- SunGuard is worth further research and development efforts.

Benefits to California

Californians are demanding reliable, affordable energy supplies that won't reduce environmental quality. Residential energy consumers will benefit from this product through lower energy bills and protection from system outages. Utilities also benefit, through reduced peak demand loads. California's economy will benefit from job creation. The environmental benefits are also substantial.

Recommendations:

Continue product development by doing the following:

- Conduct further materials and tile geometry research, for next-generation prototypes.
- Perform accelerated life tests (mechanical, water resistance, fire and UV resistance)
- Obtain commercially critical certifications (UL, ICBO, international)
- Develop distribution channels and partnerships with developers and roofing contractors.

Introduction

Background and Overview

In hot climates, where residential energy use is dominated by cooling needs, a cool roof can significantly reduce air conditioning costs. A cool roof can also lower humidity in the home and mitigate moisture-related problems caused by high attic temperatures. However, most residential roofing systems have highly absorptive surfaces that conduct large amounts of heat into the attic space.

Residential energy use has also come under scrutiny during California's current energy crisis, and customers are facing increased costs of electricity per kWh.

To date, there is no product on the market that offers both cool-roof benefits and clean, photovoltaic (PV) electricity generation. Further, most PV systems are not aesthetically attractive when installed on sloped residential roofs. PowerLight has developed a proprietary product that meets these three criteria.

The current project fits within the PIER subject area: "Building End-Use Efficiency." There is some overlap into the "Renewable Energy Technologies" and "Energy-Related Environmental Research" subject areas. The project's goal was to prove that the technical performance and economic benefits of SunGuard warrant advancing the product to commercial readiness. As a result of this project, SunGuard has completed Stage 3, Research and Bench Scale Testing, and meets the requirements of Gate 3, Proof of Feasibility.

Project objectives were to:

1. Optimize SunGuard tile geometry and materials, and perform accelerated life testing;
2. Validate product performance at an independent lab;
3. Determine energy savings to homeowners and refine target markets;
4. Develop a design for retrofit applications and refine building-integrated design.

In this report, we will present our approach for each objective, the outcome of each objective, and then present our conclusions, followed by recommendations for further research.

Project Approach

Objective 1: Optimize SunGuard tile geometry and materials; perform accelerated life testing

The following steps were taken to achieve this objective:

a) Computer modeling

Two computer modeling software options were evaluated, one existing and one a proposed custom package. The first performed poorly in comparison with field test results. The other was too expensive and required too much time (for the purposes of this project) to develop and debug. It was decided, instead, to focus on outdoor performance testing, rather than computer modeling. Furthermore, field tests offered more tangible and conclusive results than would a computer model. These field tests are discussed below.

b) Materials research

Within the scope of this grant, materials research focused on identifying first-generation materials for the top substrate of the non-PV version of the product and for the back substrate of both the PV and non-PV versions. A matrix of possible materials for these substrates was developed, comparing their advantages and disadvantages. Properties studied included cost, durability/weather-resistance, fire rating, materials handling and safety issues, UL status, strength, ease of fabrication, weight, and ease of installation of final product. The durability of several materials and adhesives was evaluated both before and after accelerated life testing.

c) Preliminary testing

Once materials were selected, experimental prototypes were constructed and tested indoors to determine the optimal distance between the top and bottom substrates of the tile. Once this distance was determined, prototypes were constructed and tested outdoors to validate thermal performance. Prototypes were also tested at an independent facility to determine the optimum distance between the glass edge and PV cell edge, to mitigate the impact of shading of one tile by an adjacent tile.

d) Prototype construction and accelerated life testing

Based on test results, a first generation tile design was finalized (building-integrated, PV version), and prototypes were constructed for internal accelerated life testing (200 thermal cycles in water) and pull tests, and for performance validation at an independent lab.

Objective 2: Validate product performance at an independent lab

The following steps were taken to achieve this objective:

A test plan was submitted to an independent lab for evaluation. Prototype tiles were shipped to the lab. Testing was conducted on two identical facilities, each modeling a typical residence roof and attic space. One roof had a 288W SunGuard system; the other roof, the control, was covered with asphalt shingles.

For this project, data was collected and analyzed over a 9-month period. The following parameters were monitored by remote: roof membrane and attic temperatures, weather data, and PV output. To study heat transfer through the tile itself, thermocouples installed throughout the SunGuard array measured temperatures of the top layer (PV), the air gap, and temperatures below the system. (The test procedure is described in full in the performance report produced by the independent lab, submitted as Appendix B; this report is proprietary and confidential.)

A final round of testing was conducted to study the impact of gaps between adjacent PV modules. The gaps were sealed for several days, and performance compared with earlier results under similar weather conditions.

Objective 3: Determine energy savings to homeowners and refine target markets

The following steps were taken to achieve this objective:

Energy savings for a typical residence were determined, by the independent lab, using performance data collected from 9 months of SunGuard system monitoring. Heat transfer from the attic space to the interior living space was calculated for the SunGuard roof and the conventional, asphalt shingle roof. A model was developed to compare the required cooling loads of these two cases, extrapolated to a 4kW system. Total energy use, cooling energy use, and PV power production were estimated for four cooling-dominated climates (Arizona, South California, Hawaii, and Florida). (This methodology is outlined in full in the performance report, Appendix B.)

Objective 4: Develop a design for retrofit applications and refine building-integrated design

The following steps were taken to achieve this objective:

Once the SunGuard concept was validated by independent testing, a design review was held to discuss (a) a first-generation design for retrofit applications (the installed and tested prototype was for building integrated applications only), and (b) how to improve the current design for building-integrated applications, in terms of ease of installation and electrical wiring, and aesthetic considerations. A further goal was to design one tile that would work for both building integrated and retrofit applications.

Project Outcomes

Outcome from Objective 1: Optimize SunGuard tile geometry and materials

1. Materials that met cost goals and most performance goals for this project were selected. Tile geometry for first-generation building-integrated prototypes was determined through indoor and field tests. The chosen materials and geometry are for first-generation prototypes only, in order to prove the product concept.

Materials were evaluated and selected for the top substrate of the non-PV tile and the back substrate of both PV and non-PV tiles. (This information is proprietary; see Appendix A for materials matrix and selections.) These materials met the cost and performance goals for this project and are approved by UL for use as roofing materials; however, neither is likely to be the best long-term solution, because neither meets all design criteria, for example, fire resistance. Further research is needed to identify materials that will meet all design criteria and, when purchased in high volume, will meet the cost-target of $2.50/sf. For the purposes of the current project, the selected materials were satisfactory.

Through indoor testing (October – November 1999) an optimal spacer height was determined. Outdoor field tests (November) verified that though the chosen tile design raises the temperature of the PV, it maintains the roof temperature slightly below ambient. Shading studies determined an optimal distance between the glass edge and PV cell edge, to eliminate shading problems at all times of year, on any roof pitch, and in any location in the US, from 7am – 6pm.

Based on these field tests, tile geometry for first-generation prototypes was determined, for both PV and non-PV tiles. (This information is proprietary; see Appendix A for description and drawings.)

Prototype tiles were constructed and subjected to accelerated life testing (200 thermal cycles in water) and pull tests. The prototypes withstood tensile forces well over typical uplift conditions.

Outcome from Objective 2: Validate product performance at an independent lab

2. A first-generation prototype SunGuard system (288W) was installed at an independent lab, on an outdoor test roof, and thermal and electrical performance data was collected for nine months; the array consisted of 34 tiles, a combination of SunGuard (without PV) and SunGuard-E (with PV).

Full test results are in the lab's performance report (Appendix B; this report is proprietary). The independent analyst reported that the SunGuard system, "shows great potential for reducing one of the major loads on air conditioning systems: heat gain through the ceiling… The reduction in solar heat gain through the roof is nearly eliminated during the critical hours of AC peak demand and utility peak demand."

The study of the impact on performance of gaps between PV modules was inconclusive. This was most likely due to the shortness of the test period, as well as reduced solar irradiance during the autumn months. It is expected that with higher ambient temperatures and/or higher wind speeds, the air gaps will impact performance positively, forcing convective heat out of the PV cavity.

Outcome from Objective 3: Determine energy savings to homeowners and refine target markets

3. Reduced energy demand and on-site electricity production were modeled for a typical residence with and without a 4kW SunGuard system, using a computer model and empirical test results, to estimate energy savings. Target markets were further refined.

The lab's model predicted that for a typical residence, on an average August day, a 4kW SunGuard system would reduce AC system load due to heat gain through the roof by 90%. Applying this model to different states projected significant energy savings, for Florida, Arizona, Southern California, and Hawaii. (Specific results are discussed in Appendix B.)

It was expected that the general target market would be hot, cooling-dominated climates. During this contract, target markets were further refined as the hot, inland areas of California; Arizona, Hawaii, and Florida; as well as Europe and Japan. More extensive market research was conducted outside the scope of this contract.

Outcome from Objective 4: Develop a design for retrofit applications and refine building-integrated design.

4. A first-generation design was developed for retrofit applications. Based on field test results, the building-integrated design was refined.

Retrofit
The retrofit design uses a standoff to integrate the PV with an existing asphalt shingle roof. Typically, PV is mounted on an existing roof with a "roof jack" brackets. The benefits of the standoff over the roof jack are as follows:

Standoffs would be:
- Nailed in an area covered by a shingle and the adjoining standoff, giving twice as much roof coverage.
- Interconnected, resulting in higher wind resistance, and thus requiring fewer roof penetrations.
- Aesthetically advantageous, giving an integrated appearance.
- Overlapped, which cools the PV by optimizing natural convection; this mitigates the "chimney effect" seen in roof jack systems.

In addition, standoffs would use traditional roof flashing techniques, won't require special adhesives or sealants, and would be fabricated from inexpensive sheet metal (Kynar-coated for weather resistance).

Building-integrated
Based on field tests of prototypes, the building integrated design was reviewed and modified to include a "modular pan." In this design, custom-fabricated supports would be adhered to the back of the PV panel, in the factory. Metal pans would be fabricated in a stamping or roll-forming process. These units would be assembled on site, using pin connectors. Total cost of materials (excluding PV) would be less than the $2.50/sf target cost.

This concept, still in its infancy, has the most promise of designs to date. The metal pan could be installed over existing shingles, provided that the edge of the array incorporates a waterproof flashing. Further design work is necessary, including ridge, eave, and edge details for building integrated applications.

Conclusions and Recommendations

Conclusions

- As shown in internal and independent testing, SunGuard nearly eliminates heat flow through the roof during the critical hours of AC peak demand and utility peak demand.
- Thermal properties can reduce AC system load due to heat gain through the roof by 90%. When the PV tiles generate electricity, SunGuard may result in total energy savings of 28%-35% in target markets.
- Target markets are new construction for the building-integrated version of the product, and retrofit (and re-roofing) applications over existing asphalt shingle roofs, on buildings in hot,

cooling-dominated climates. These climates include the hot, inland areas of California; Arizona, Hawaii, Florida. Europe and Japan are also target markets, due to extensive public incentives for PV.
- Retrofit designs will use standoffs to integrate PV with typical asphalt shingles. The modified building-integrated design will incorporate a "modular pan."
- SunGuard is worth further research and development efforts.

Commercialization Potential

Based on work performed under this grant, the SunGuard concept has significant commercial potential. To be commercially successful, this product will have a combination of features not addressed by currently available residential PV technologies: simplified installation and electrical wiring, aesthetic appeal, improved PV performance, improved thermal performance, and low cost. At the target cost of $2.50/sf (long-term, under high volume manufacturing), the product will be competitive with other premium roofing products; it will have at least twice the life expectancy of asphalt shingles. In sum, homeowners can buy good-looking, inexpensive roofing materials, but SunGuard's appeal will be its power to cool the home and generate electricity <u>at the same time</u>. As electricity prices rise, the demand for such a product is growing rapidly.

Recommendations

- Conduct further materials and tile geometry research, for next-generation prototypes.
- Perform accelerated life tests (mechanical, water resistance, fire and UV resistance)
- Obtain commercially critical certifications (UL, ICBO, international)
- Develop distribution channels and partnerships with developers and roofing contractors.

Benefits to California

Within the limited time/scope of this grant, PowerLight was able to make progress on a product that, in the long run, will benefit Californians in a variety of ways. The SunGuard product, once developed and manufactured in high volume, will be an affordable, aesthetically attractive product that offers substantial energy savings to residential energy consumers. On-site electricity generation combined with a reduction in peak energy demand will also reduce peak utility loads – and system outages – lowering the public cost of California's energy crisis. SunGuard will increase comfort within the home, by reducing humidity and other moisture problems. Based on HVAC energy savings and reduced energy usage, and assuming a 5% market penetration in warm California climates, a SunGuard system could conserve per average homeowner (3kW system) 2674 MBTU, 351 barrels of oil, 186 tons of carbon, .8 tons NOX, and 1.3 tons SOX, over the product lifetime. Finally, California's economy – at the state and local levels – will benefit from jobs created (and resulting tax revenue) in commercial manufacturing of this product.

Development Stage Assessment

Development Assessment Matrix

Stages / Activity	1 Idea Generation	2 Technical & Market Analysis	3 Research	4 Technology Develop-ment	5 Product Develop-ment	6 Demon-stration	7 Market Transfor-mation	8 Commer-Cialization
Marketing								
Engineering / Technical								
Legal/ Contractual								
Risk Assess/ Quality Plans								
Strategic								
Production. Readiness/								
Public Benefits/ Cost								

Marketing/Connection to the Market. Initial market research was conducted. Further market research, to clarify customer needs and market potential estimates, was done (and continues) outside the limited scope of this grant.

Engineering/Technical. Performance goals (product specifications) were set for this product outside the limited scope of this grant, but based on the positive results of the grant-funded technical feasibility tests. The product's estimated low absorptance value indicates technical feasibility of the product concept. Work continued, past the grant's scope, to address remaining technical problems. The test plan presented in the report was adequate for this stage of research and development. A test plan has been written for future field tests; it has been evaluated and accepted by an independent lab.

Legal/Contractual. A patent has been issued for this product. Subsequent patents are currently being developed. No patent issues have arisen as yet. The commercializer for this product will be PowerLight. No sales data is yet available. When it is available, sales data will be submitted to the Commission, per contract requirements.

Environmental, Safety, Risk Assessments/ Quality Plans. These elements of product development were not part of the scope of work for this grant, though during these initial stages of product development, environmental and safety concerns were addressed. A quality plan has not been developed. Product life cycle analysis was conducted for potential materials; future life cycle tests are planned. Five areas of risk have been analyzed: market, regulatory, technology, management and execution, and competition. A plan is in place to resolve each risk area.

Strategic. This product has no known critical dependencies on other projects under development by PIER or elsewhere. It is believed to be unique to this project with limited or no impact on other PIER projects.

Production Readiness/Commercialization. Beyond the scope of this grant, PowerLight investigated its options for production and commercialization. It is expected that the commercializer will be PowerLight.

Public Benefits/Costs. The empirical results of this project – i.e. proof of the SunGuard concept – are expected to significantly increase the calculated California public benefit-cost ratio. Project results support continued product development. The benefits to be derived from the product have improved since this project was completed, due to research advances (outside grant scope) and increases in residential energy prices.